UAVSAR G-III Precision Autopilot Overview and Results

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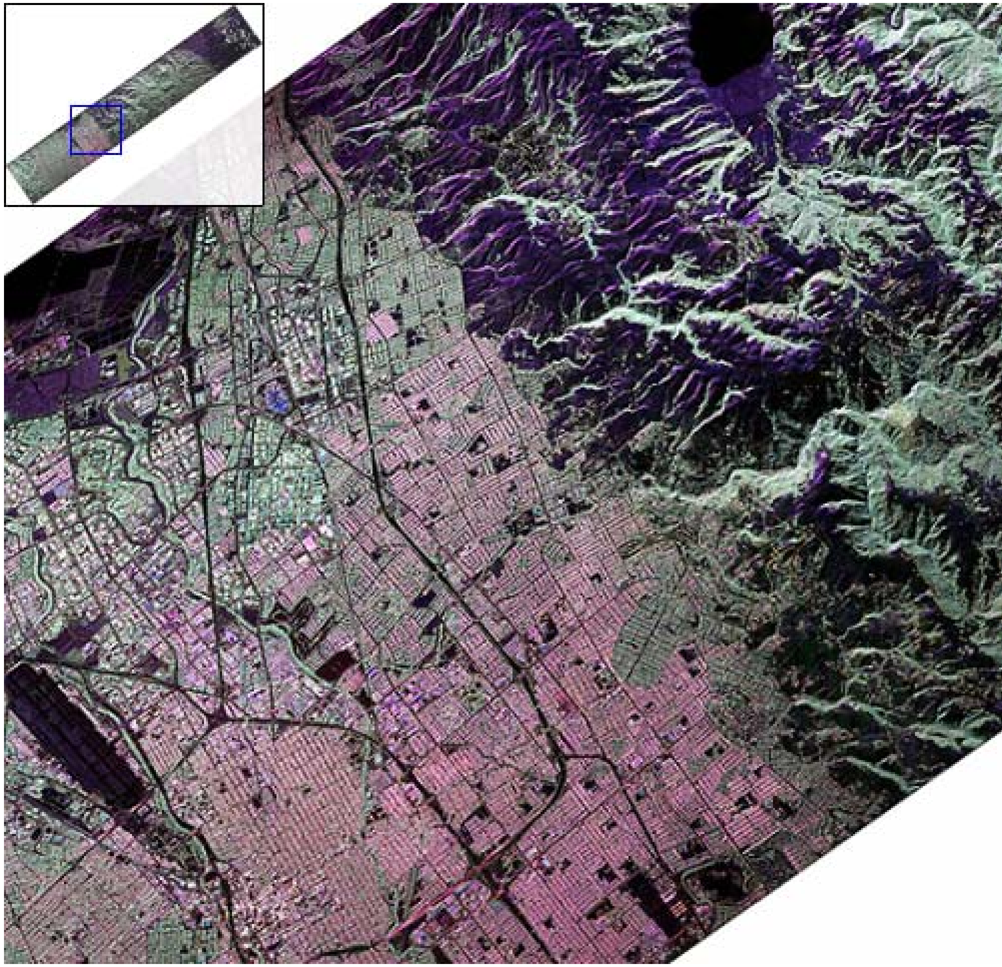
UAVSAR Primary Objectives

- Develop a miniaturized, polarimetric, L-band SAR for use on a UAV.
- For accurate measurements of earth deformation due to
  - Earthquakes
  - Volcanic activity
  - Polar ice cap changes
- Measured using repeat pass interferometry which requires
  - Accurate knowledge of SAR position
  - Two SAR images from nearly the same position (PPA task)
  - Complex data processing to compare phase shift between images



San Jose, CA

UAVSAR Enabling Components

- JPL developed a global dGPS for accurate SAR position
  - Inmarsat and Iridium are used for differential corrections with pole to pole coverage
  - 1 σ accuracy is estimated at 10 cm horizontally and 20 cm vertically
  - Position is updated every second with 100 to 280 ms of latency
- The GIII is a transitional platform
  - Aids researchers in SAR development
  - Has unlimited access to national airspace system (NAS), unlike a UAV
- Platform Precision Autopilot (PPA) was developed to enable repeat pass precision in support of UAVSAR for the GIII

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NASA Dryden's G-III (502)

- **Aircraft Dimensions**
  - Wing
    - Span 77 ft 10 in
    - Area 934.6 ft^2
  - Length 83 ft 1 in
  - Height 24 ft 4.5 in
  - Large Internal Volume (1500 cu. Ft.)
  - Max of 12 seats
- **Aircraft Performance**
  - Max Mach – 0.85
  - Max Operating altitude – 45Kft
  - Typical Cruise – 400 to 500 kts
  - Range – ~3000 nautical miles
  - Climb Rate – up to 4,000 fpm
- **Aircraft Instrumentation**
  - Control surface positions
  - Flight Director (FD)
  - Air Data Computer
  - INS
  - Aircraft GPS
  - On-board experiments
  - Data capture and processing system (DCAPS)

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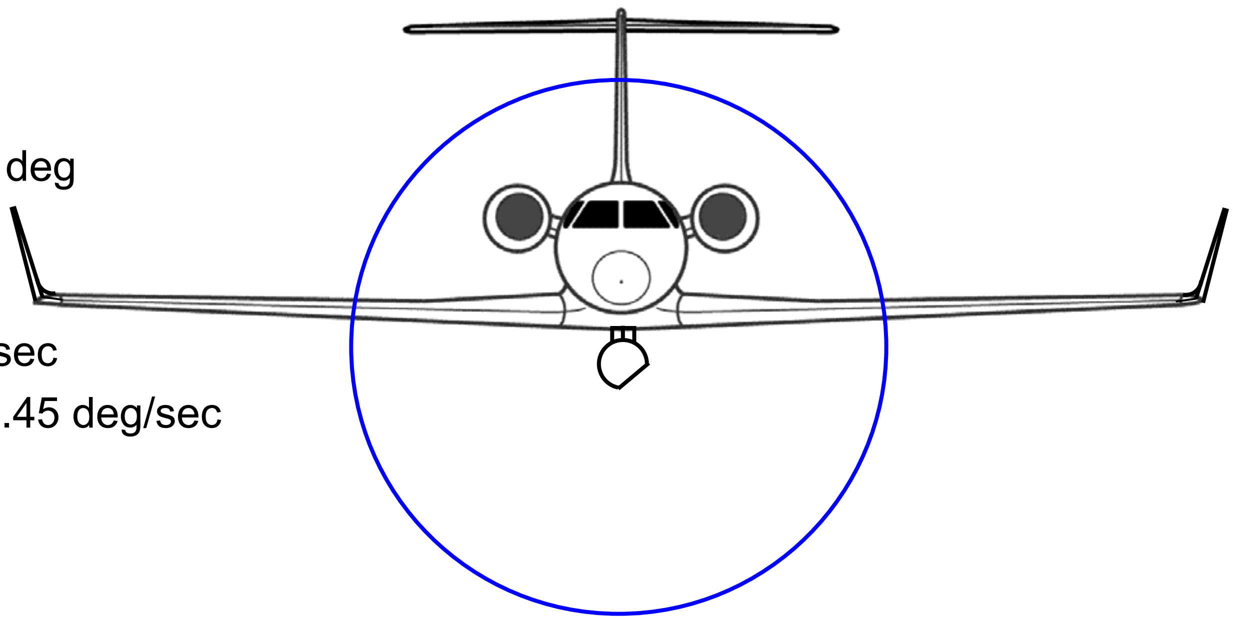
The PPA Requirement

- The PPA shall fly within a 5 meter radius of the course for at least 90 percent of the time in conditions of calm to light turbulence
  - In one second, the GIII travels the distance of 2.5 football fields (230 m) and would be outside this 5 m radius with a course misalignment greater than 1¼ deg
  - The factory installed GIII autopilot at best tracks within
    - ± 8 m in altitude
    - ± 40 m in cross track
- JPL desired
  - Angles
    - Roll and pitch < 5 deg
    - Yaw < 15 deg
  - Rates
    - Roll less < 1 deg/sec
    - Pitch and yaw < 0.45 deg/sec

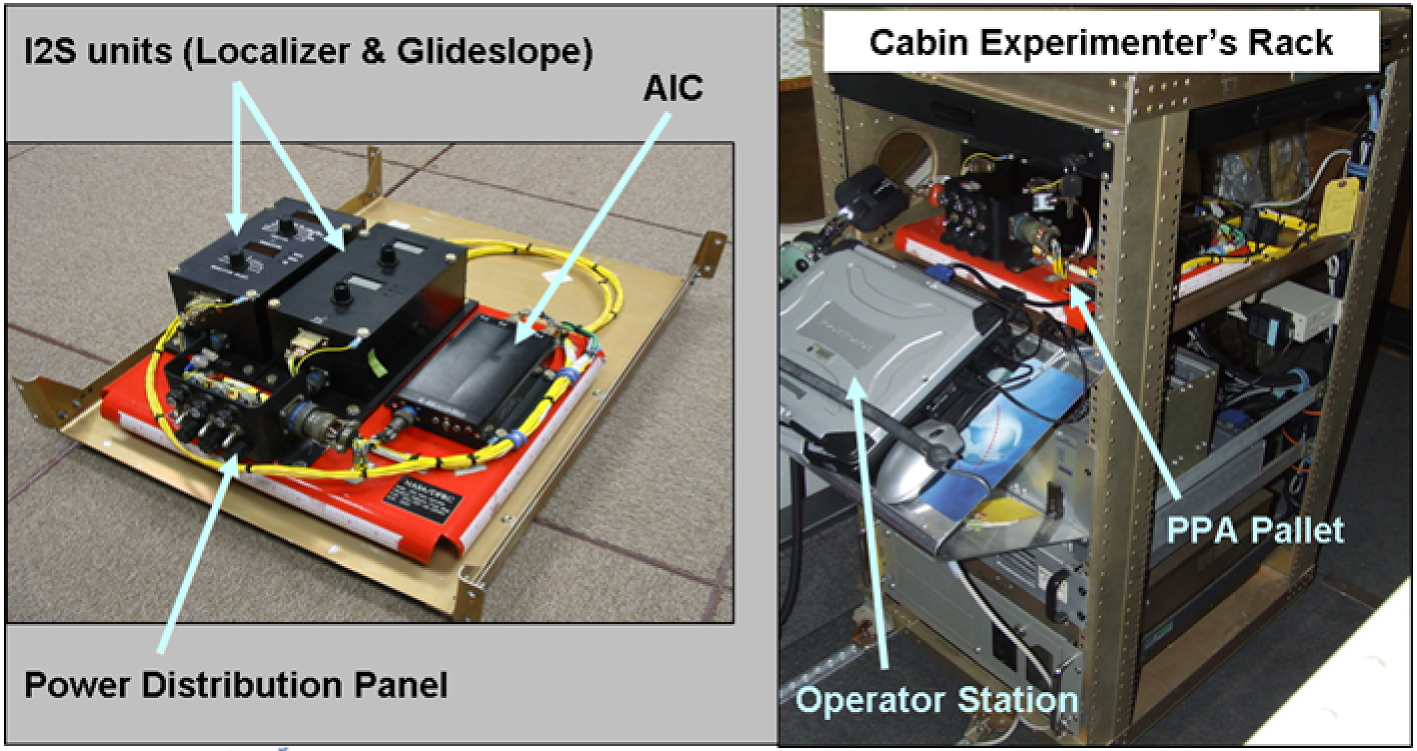


PPA Software

- The PPA software was coded in Simulink and consists of three major routines
  - Navigation
    - Kalman filter combining accurate 1 Hz dGPS position with 16 Hz INS attitudes
    - Necessary to project position between dGPS updates and correct for latency
  - Guidance
    - Defines courses between two waypoints
    - Outputs error signals for altitude and cross track
  - Controller
    - Altitude
      - PID with Nz
        - Proportional and integral use altitude error feedback
        - Derivative uses inertial vertical velocity feedback
        - Nz uses inertial vertical acceleration feedback
    - Cross track
      - PID using only cross track error feedback

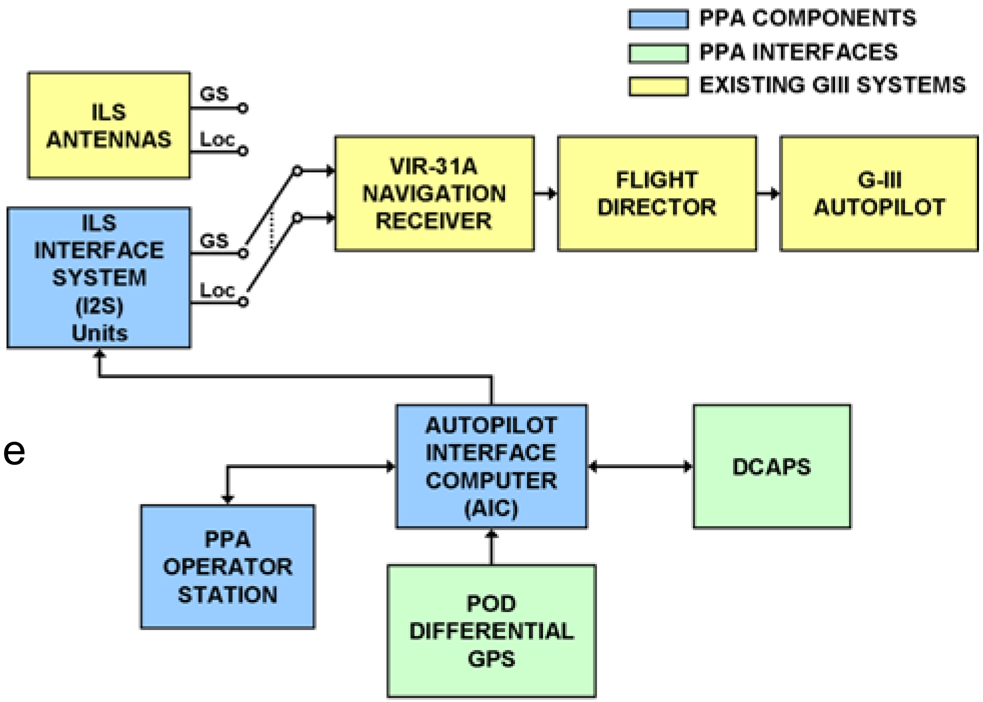
The PPA Hardware

- The three major hardware components in the PPA are
  - Autopilot Interface Computer (AIC) is a Phytec mpc565
    - With autocoded PPA control software
  - Two ILS Interface System (I2S) units which convert AIC command voltages to modulated radio frequency (RF) signals
  - Laptop computer which performs the operator station functions



Aircraft Interface

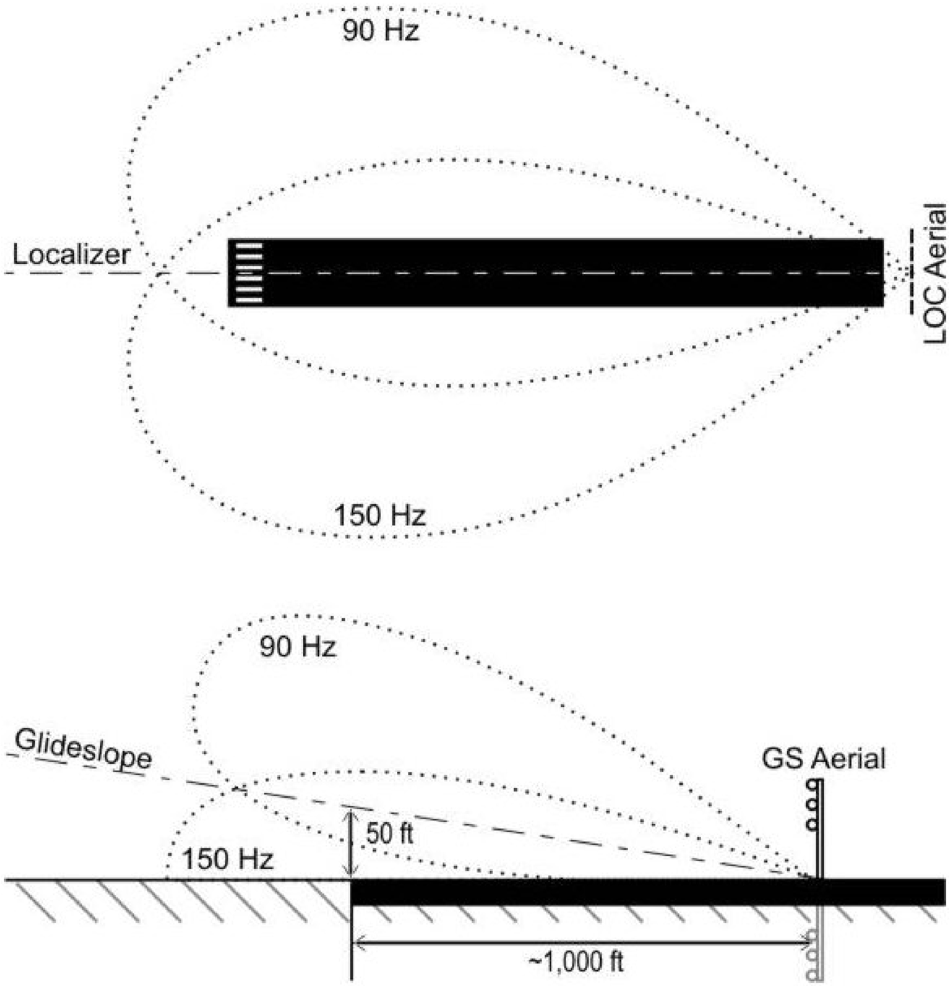
- The AIC interfaces with the GIII through RF switches between the navigation receiver and ILS antennas
  - Disadvantages of the AIC interface
    - Approach mode initiates a 3 deg pitch down with close to zero input
    - Requires extra hardware to convert commands to RF
    - Requires non-zero AIC output for zero navigation receiver output
      - The non-zero bias required changes with time
      - Noise makes determination of zero navigation receiver output difficult
    - Downstream hardware (Navigation Receiver, FD, and GIII autopilot)
      - Amplifies command
      - Have additional inputs that affect output
  - Advantages of the AIC interface
    - Retains factory safety limits
    - Quickly returned to baseline with the flip of a switch



Instrument Landing System

- ILS consists of two radio transmitters each with a signal at 90 Hz and 150 Hz
  - VHF transmitter for Localizer
  - UHF transmitter for Glideslope

- Localizer and Glideslope receivers on aircraft measure Difference in Depth Modulation (DDM) of the 90Hz and 150 Hz signals.
  - DDM of localizer signal indicates if aircraft is left or right of centerline
  - DDM of glideslope signal indicates if aircraft is above or below glideslope
  - DDM of zero indicates aircraft is along centerline or glideslope



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First Flights

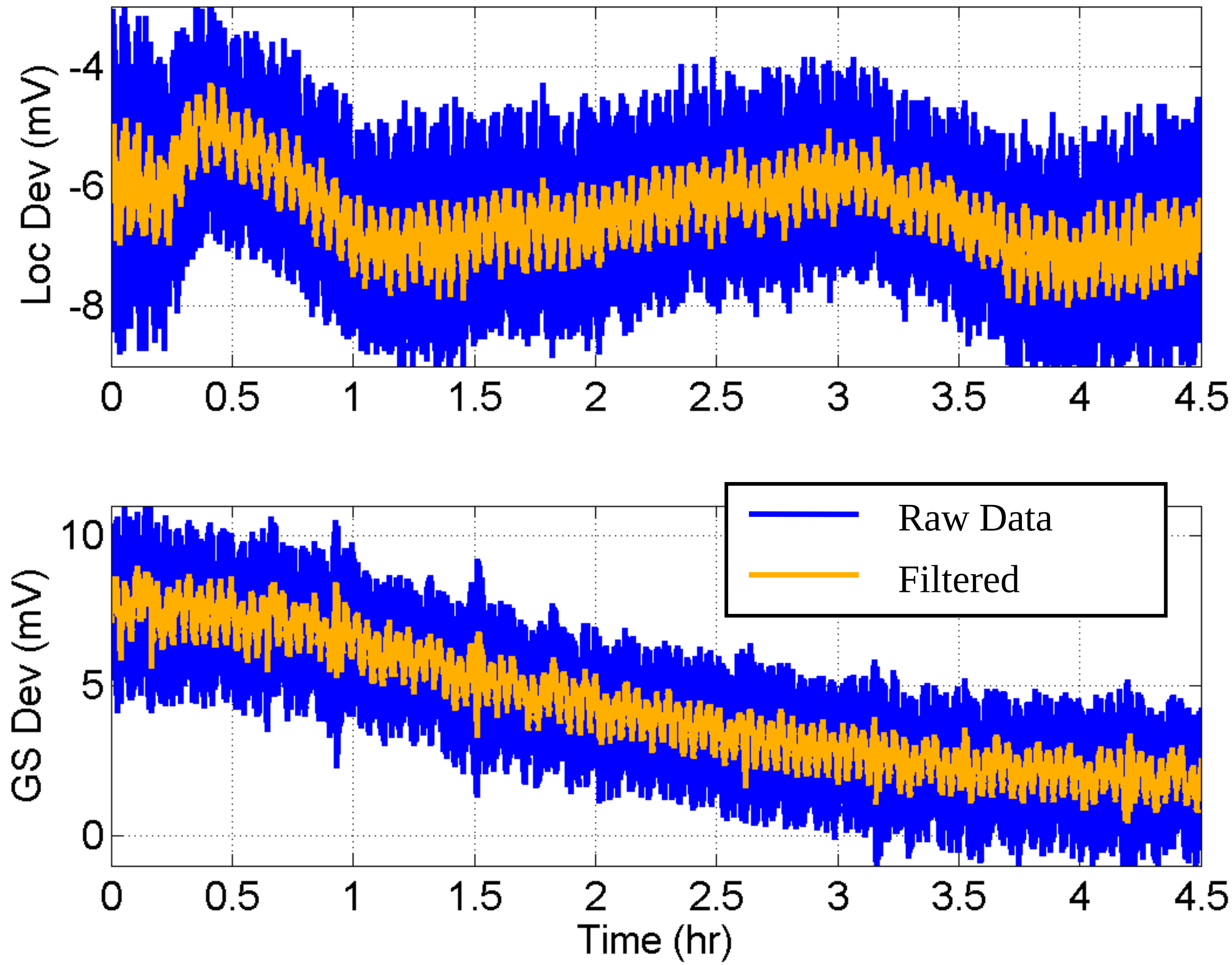
- The first three flights were open loop
  - The first flight consisted of step commands from the PPA with increasing magnitude
    - The FD commanded and unexpected pre-programmed pitch down maneuver
    - The rest of the flight was flown in altitude hold mode to continue with roll control authority testing
  - The second flight was a continuation of the first
    - A mitigation for the pitch down was successfully tested
    - The step commands were tested in both pitch and roll channels
      - Pitch response was incredibly small
  - The third flight was flown using the factory installed GIII autopilot while the PPA was engaged but not coupled
    - This data was used to determine that the polarity was correct for all the feedback loops

Lessons Learned

- FD pitch down mitigation
  - It was determined that the copilot could hand fly the aircraft with touch control steering (TCS) button depressed to bypass the initial 3 degree pitch down
    - The TCS disconnects the actuators from the autopilot while depressed
  - The FD cue on the copilot display shows the pitch down intent (~15 sec)
- Softer autopilot gains
  - The standard factory GIII autopilot pitch gains were approximately 1/10th the values in the vendor supplied simulation model
    - This required the use of higher PPA gains
- FD
  - Amplification was initially determined in ground testing prior to flights
    - Gains were found to be three times greater in flight (60 pitch and 150 roll axes)
  - Modeling the additional feedback loops with flight data was ambiguous
- The derivative of the navigation routine position had 1 Hz spikes at every dGPS update which limited lateral damping
- I2S and navigation receiver drift and noise are shown in the next two slides

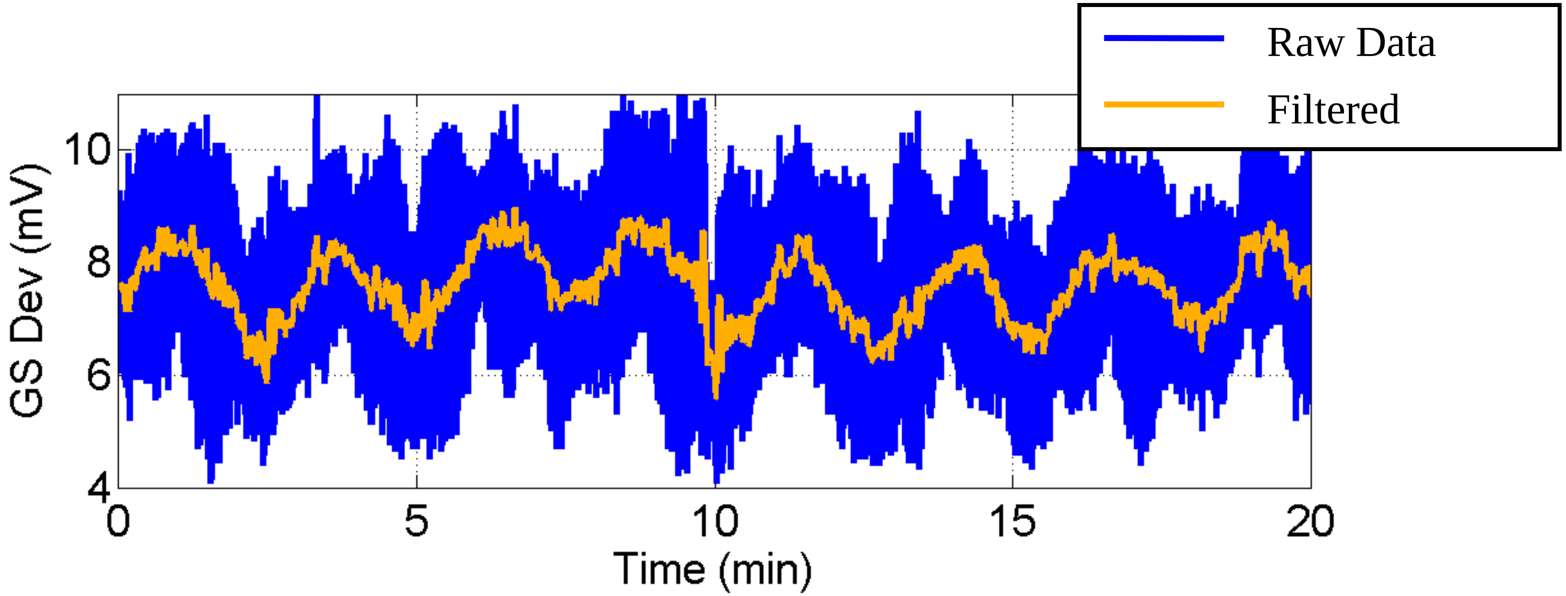
I2S and Navigation Receiver Drift

- Navigation receiver output with constant input
  - Low frequency drift
- At engagement the non-zero output results in an initial vertical velocity and roll transient
  - Increasing the time required to intercept the course



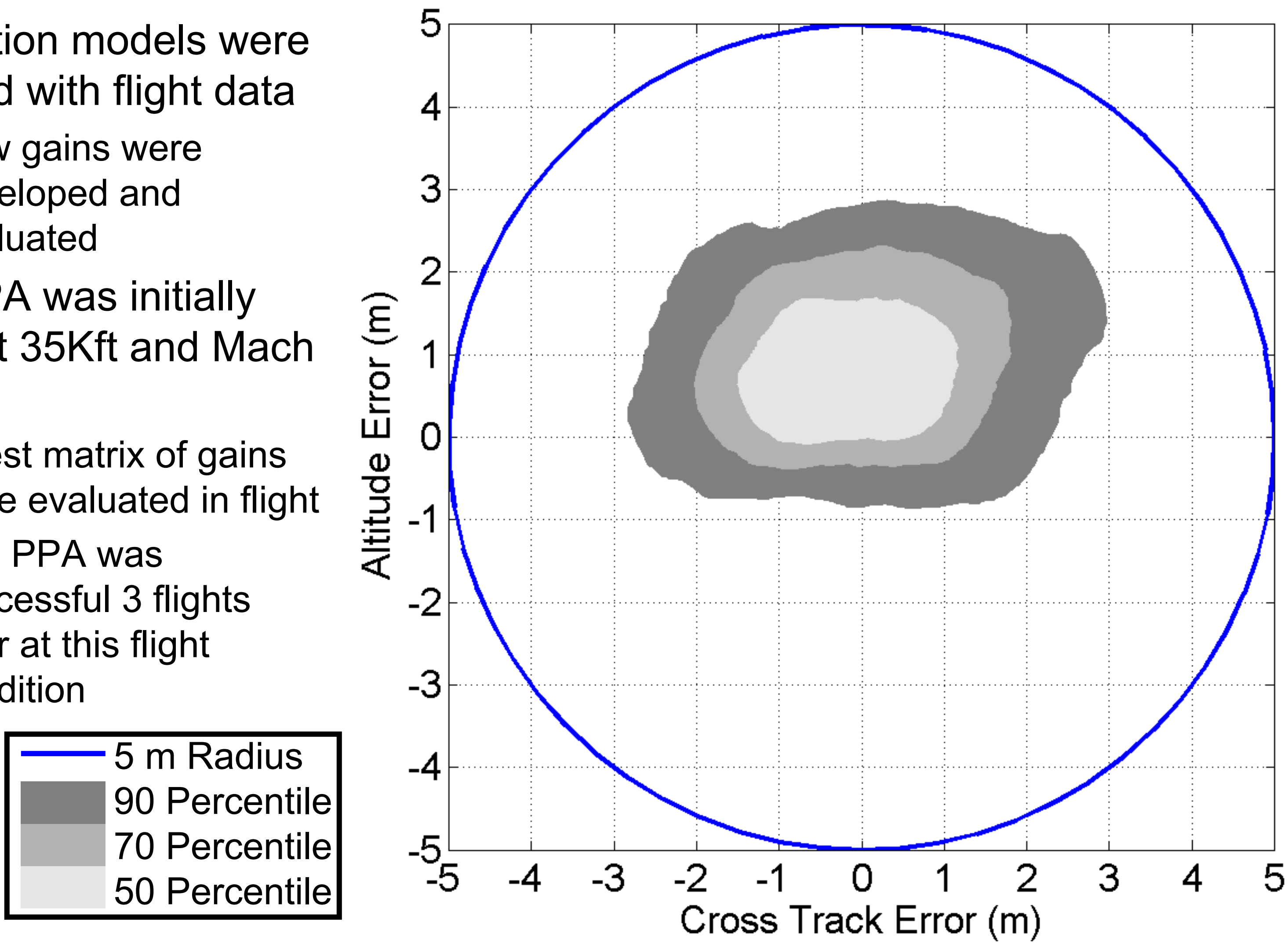
I2S and Navigation Receiver Noise

- Same data from the last slide with smaller time scale
- PPA operator inputs bias in both channels to zero navigation receiver output
  - Manually difficult with noise and drift
  - An algorithm was developed to automate this at the operator station
- PPA controller
  - Has plenty of authority to quickly remove the drift with the integral loop
  - Commands at this point are ~ ±2 mV
- The FD effectively filters this noise from the system



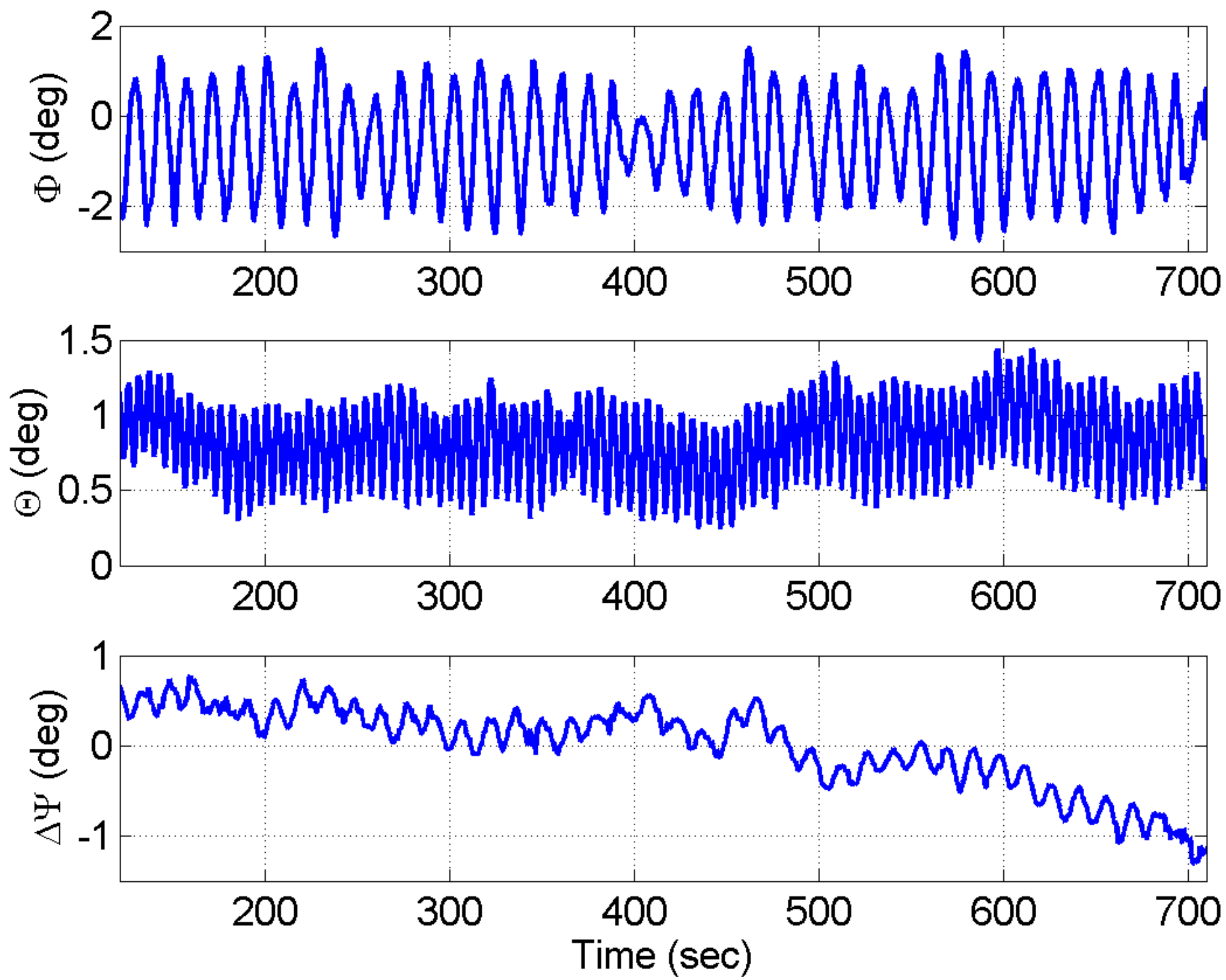
First Success

- Simulation models were updated with flight data
  - New gains were developed and evaluated
- The PPA was initially flown at 35Kft and Mach 0.75
  - A test matrix of gains were evaluated in flight
  - The PPA was successful 3 flights later at this flight condition



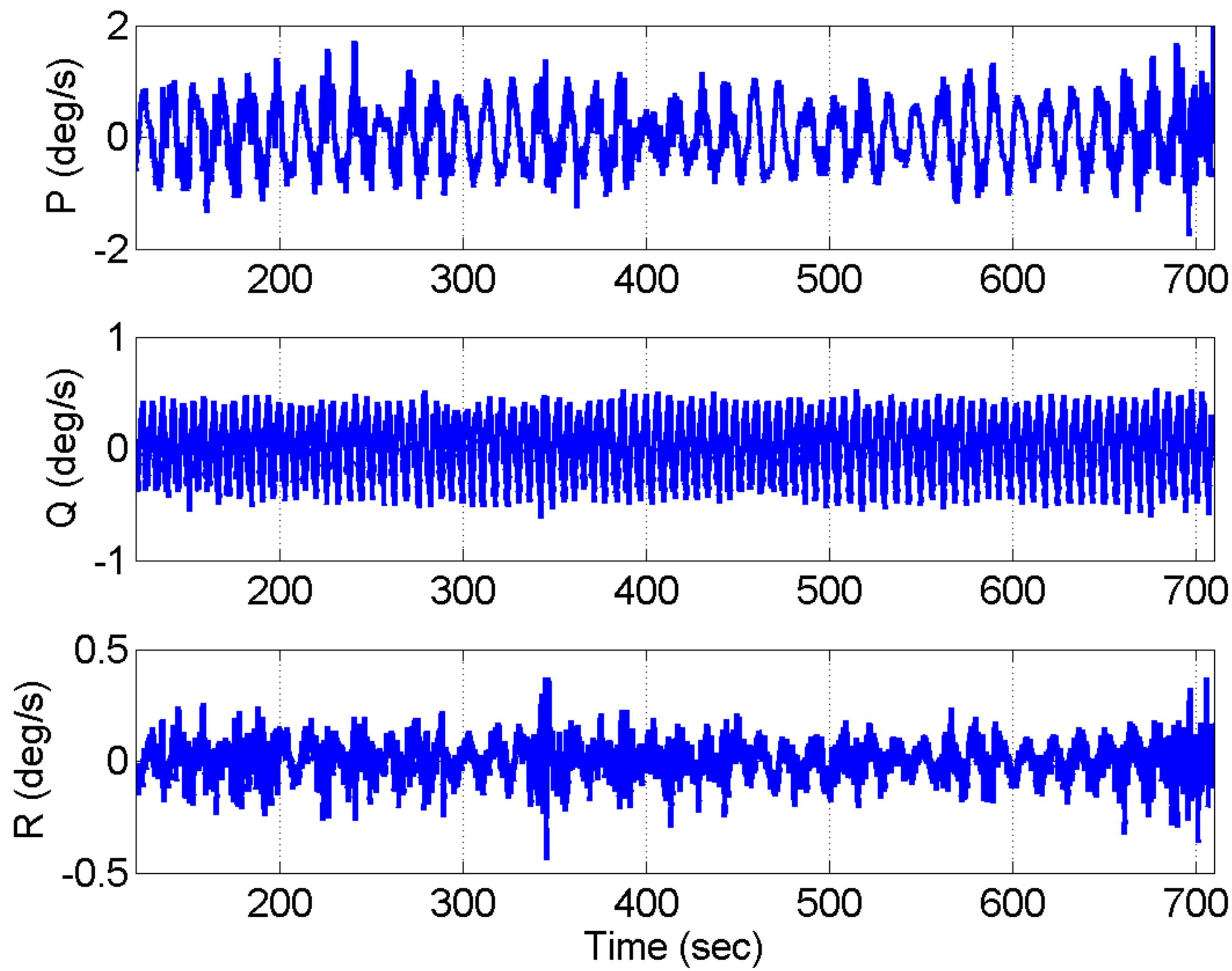
Euler Angles

- Angles were within desired values
- Roll exhibited wing rocking with a 14 second period
  - Result of derivative of cross track error with 1 Hz dGPS updates
  - Ride quality suffered



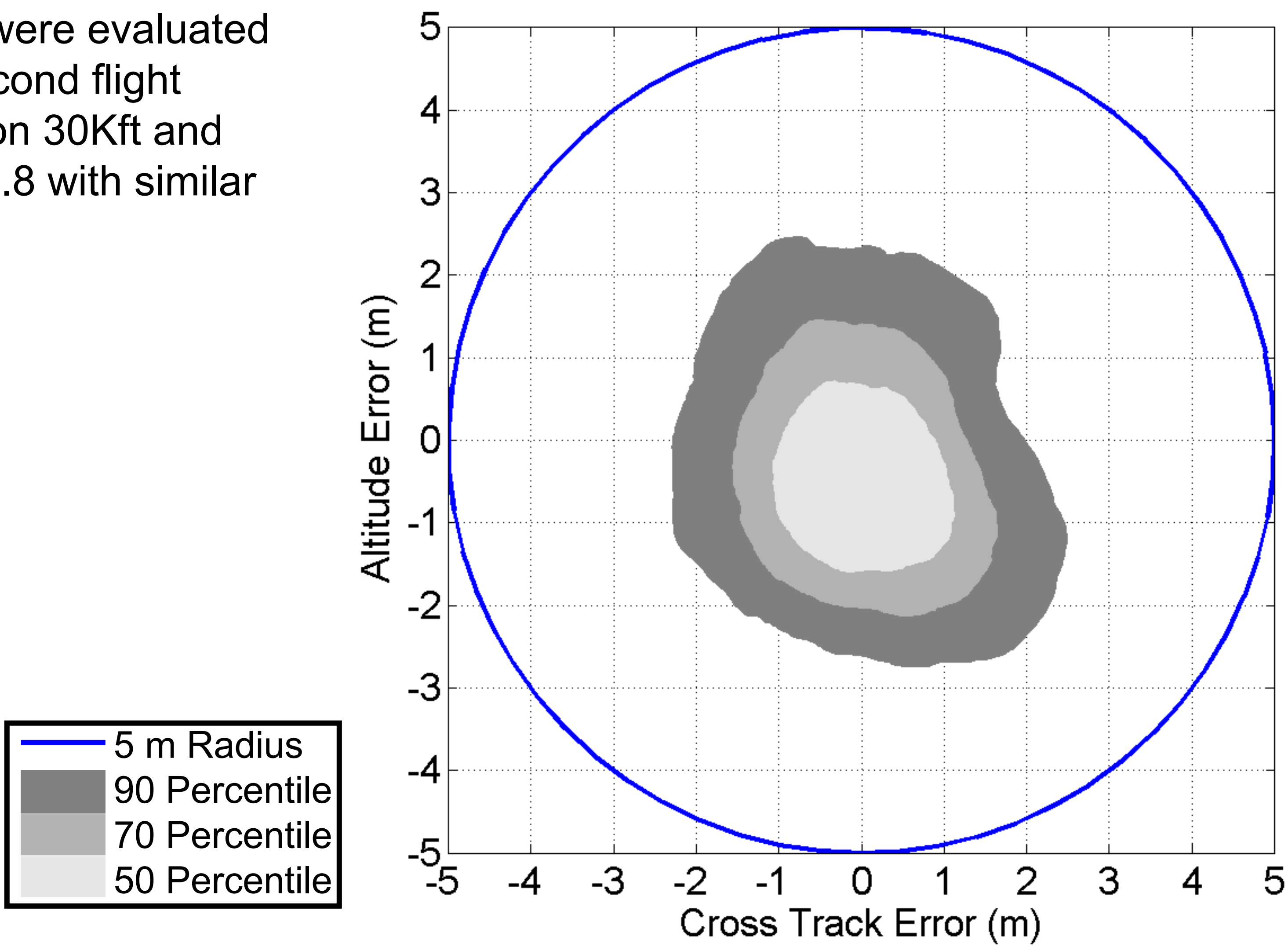
Body Rates

- Roll rate was greater than desired value
- Pitch and yaw rates were within the desired values
  - The yaw rate was controlled by the yaw damper



Second Flight Condition

- Gains were evaluated at a second flight condition 30Kft and Mach 0.8 with similar results

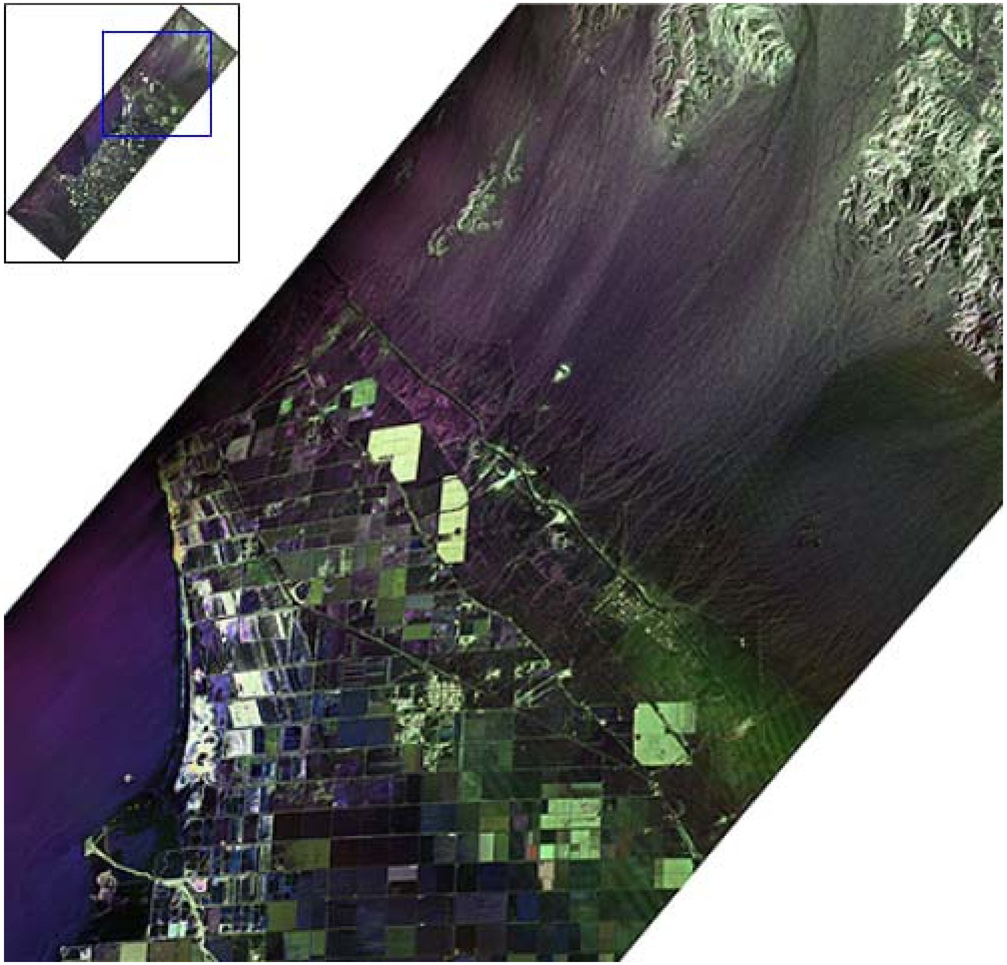


Will the PPA Fly Slower?

- Initial testing of the UAVSAR pod required substantially lower ground speeds
- The PPA was tested at these lower speeds
  - The pitch rate was dramatically higher
    - Because FD pitch rate limits increased at lower speeds (found through more ground testing)
    - And the PPA command was continuously against the FD pitch rate limits
  - Increased pitching resulted in normal acceleration of ± 0.1 g’s with a 5 second period
    - Ride quality really suffered

PPA Final Updates

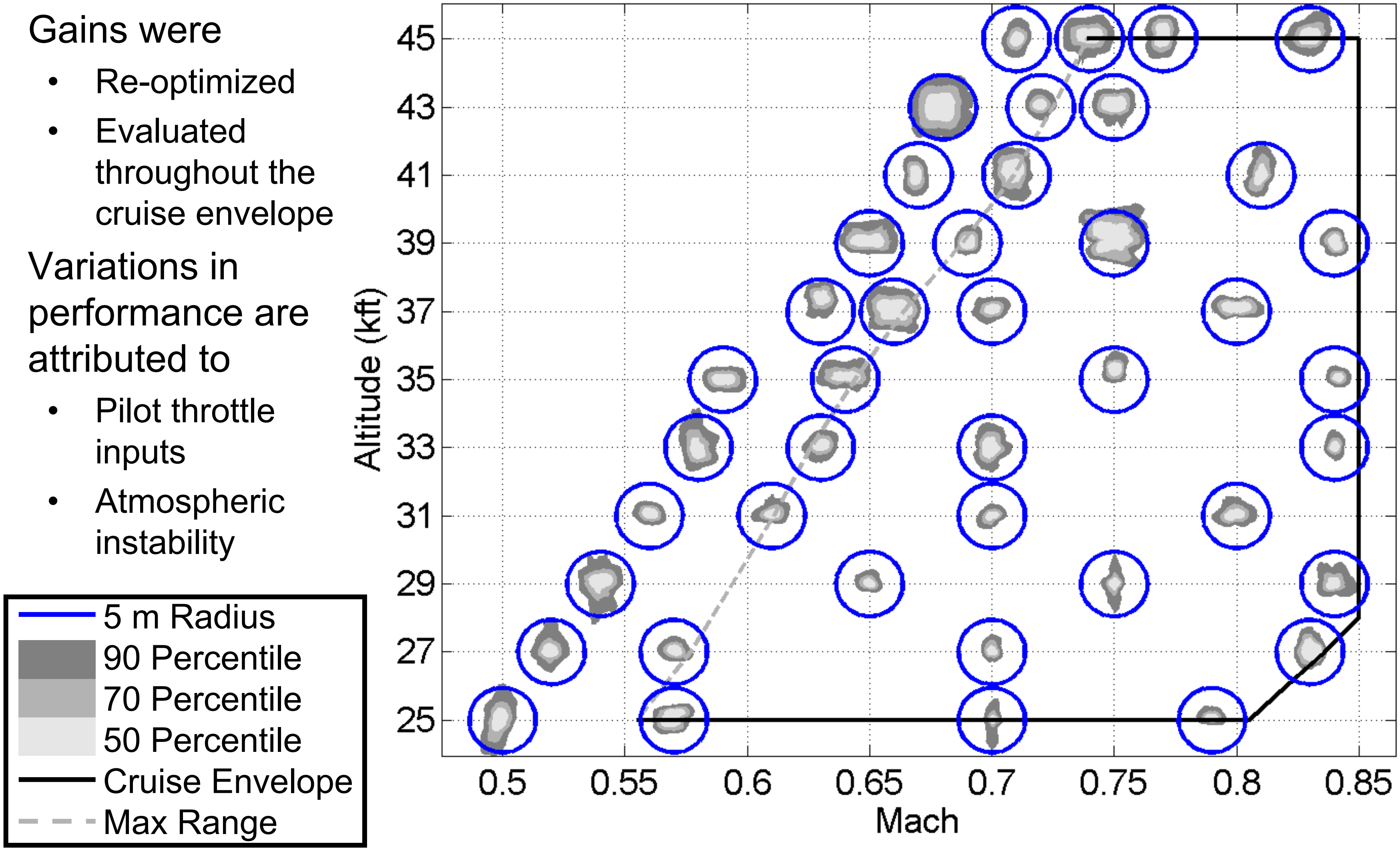
- Improved command resolution
  - Reduced reference voltage in digital to analog converter
  - Reduced I2S amplification
- Replaced Nz with pitch rate feedback for increased damping
  - Reduced pitch rate especially at low speed
  - Slowed the pitch response to external disturbances (power changes or atmospheric)
- Track angle error used in place of derivative of cross track error
  - Reduced roll activity from derivative spikes
  - Gain is reduced by 30 percent outside 1000 feet increase intercept angle with larger initial offsets



Southeast Corner of the Salton Sea

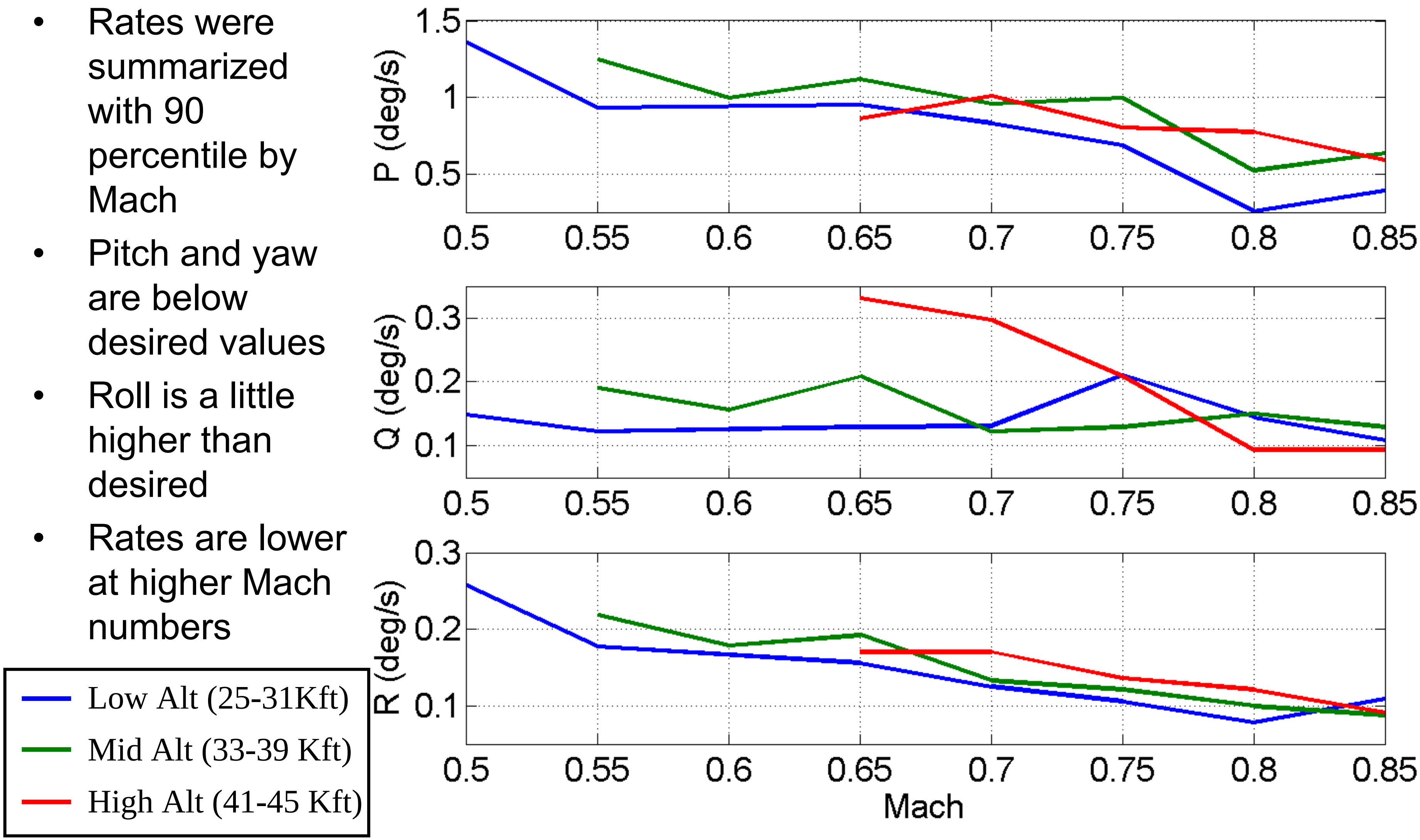
Performance Throughout Cruise Envelope

- Gains were
  - Re-optimized
  - Evaluated throughout the cruise envelope
- Variations in performance are attributed to
  - Pilot throttle inputs
  - Atmospheric instability



Angular Rates

- Rates were summarized with 90 percentile by Mach
- Pitch and yaw are below desired values
- Roll is a little higher than desired
- Rates are lower at higher Mach numbers



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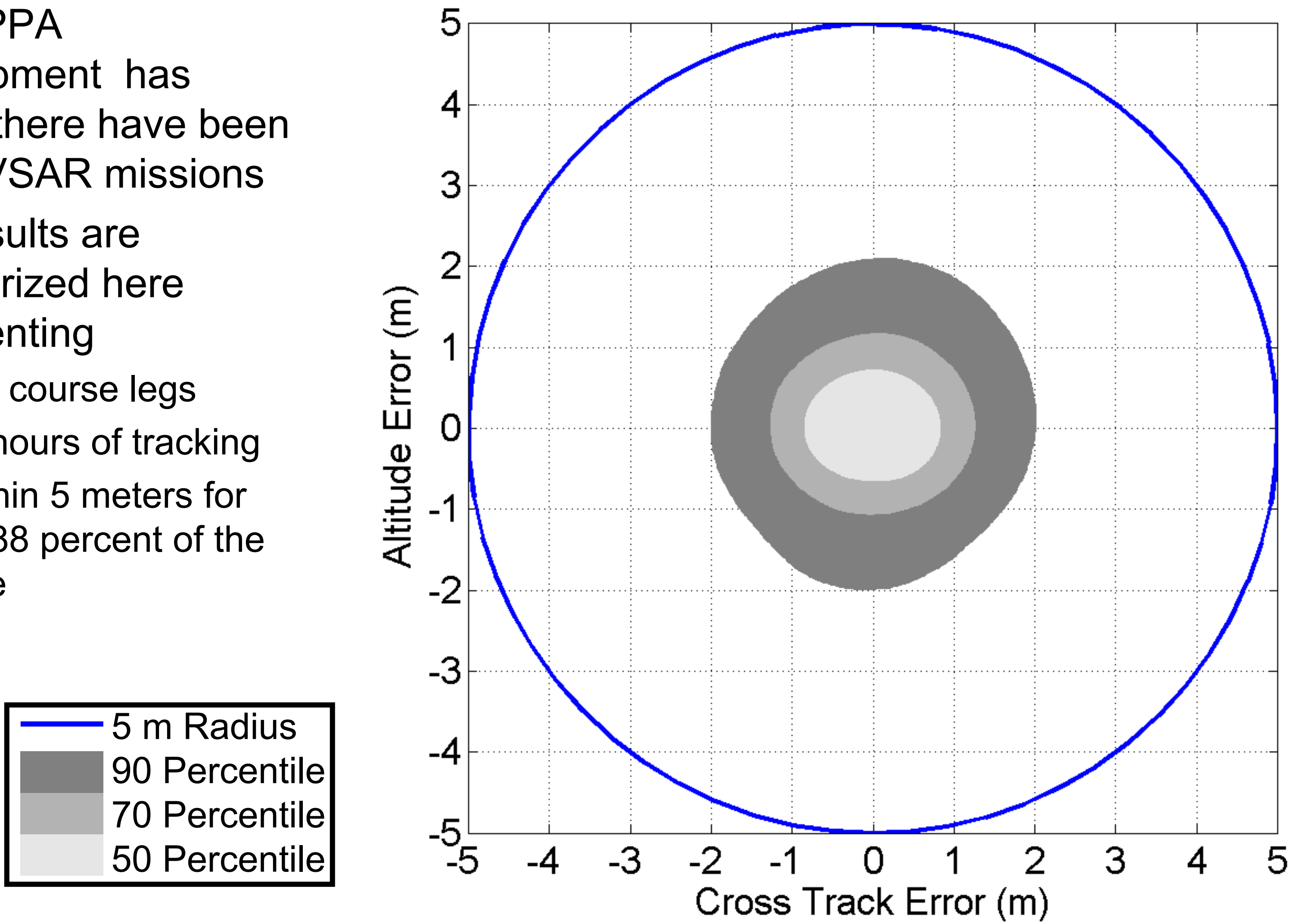
UAVSAR Mission Performance

- Since PPA development has ended there have been 25 UAVSAR missions
- The results are summarized here representing
  - 224 course legs
  - 29 hours of tracking
  - Within 5 meters for 99.88 percent of the time



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Conclusions

- The PPA system has:
  - Demonstrated success in meeting its requirement of flying the GIII within 5 meters of a course for at least 90 percent of the time in the presence of light turbulence while meeting most of the desired body rates and angles
  - Successfully been used in the field for science missions since December 2007
- The customer, JPL, has noted the PPA performance most often exceeds the requirements

Questions?

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